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Using product and manufacturing system platforms to generate producible product variants

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Abstract

Product platforms have proven efficient as a means to reduce lead-time and increase product quality simultaneously. When using platforms to generate a family of products, the number of variants that need to be managed in manufacturing increases. To succeed with this, the manufacturing system needs to be maintained in a similar level of flexibility as the product platform. However, there is seldom a joint decision behind each and every conceptual product variant during development, regarding capability in manufacturing. For example, when considering producibility, some product variants require better tolerances than what the manufacturing processes can deliver. This uncertainty can be reduced, by making producibility analyses of a set of conceptual product variants. By performing several different analyses, knowledge can be gained, and joint decisions can be made about cross product-manufacturing aspects. The activities can be systematically arranged to gradually eliminate unfeasible conceptual product variants. In this paper we show how an integrated PLM architecture can be used to create sufficient knowledge as a basis for joint product and manufacturing decisions. The utmost company benefit of this is to reduce lead-time by taking manufacturing capability into account when developing product families.

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Keywords: Product Platform; Manufacturing Platform; Producibility; PLM

1. Introduction

Platform-based design has traditionally focused on serving manufacturing with a low number of different parts. However, there is a shift in research towards, and an industrial need for, supporting reuse in the development phases. As a consequence, there is a risk that manufacturing aspects are not considered to the same degree, and the pursuit for a feasible producible variant will drive design rework activities, such as physical verification on a high number of variants, which is both time-consuming and costly. To maintain efficient manufacturing throughout this new paradigm, it is essential to better assess the producibility of the platform, and thus the family of variants that can be derived from it.

Modern computer aided engineering (CAE) tools are today capable of simulating various manufacturing capabilities, such as welding operations and robot paths. However, these simulations are typically used for process planning and as pre-production verification. At this late stages, changes to the product design are significantly more expensive than in the conceptual phases, due to the amount of engineering hours already put in into the detailed design, simulation, and possibly even physical prototyping, testing and verification.

Being able to better assess producibility in the conceptual phases would help propel the development towards a product adapted to desired manufacturing conditions, and minimize late changes. This type of concurrency has proven beneficial against late changes to products [1].

Set-based concurrent engineering (SBCE) advocates elimination of unfeasible designs based on intersecting design spaces from different domains [2], for example design and manufacturing. To ensure validity in design decisions, these need to be based on facts, rather than assumptions about the design and the manufacturing system.

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This paper explores the possibility to use simulations related to producibility to narrow down the design space. To accomplish this, a number of design modeling and assessment tools are integrated into a Product Life Cycle Management (PLM) architecture. This architecture is used to virtually configure and assess a large number of possible concept variants simultaneously. The knowledge gained through this process is used to eliminate the concept variants with inferior producibility.

2. Research Approach and Scope

The context of this paper is producibility of platform variants in conceptual phases of development, and specifically the integration of CAx systems, displaying a PLM approach, as well as adequate and supporting platform processes. It is illustrated through a realistic case from the aerospace industry. The case is prepared in collaboration, and is based on a long running relationship, with industrial partners. The purpose is to get access to in-depth knowledge of products, manufacturing equipment and process knowledge. System specialists have been interviewed and relevant documentation, such as design guidelines and process descriptions, has been accessible and reviewed. During workshops, system specialists and researchers have revised and refined models in collaboration. A research question is formulated to drive the research: *how can a PLM architecture support assessment of producibility in platform concept development?*

3. State-of-the-art

This section presents a body of research related to platform development of products and manufacturing systems. It also gives an overview of producibility and IT support, commonly used in product and manufacturing development.

3.1. Platforms

Using a platform as a means of reusing knowledge has been receiving significant attention over the past decade [3]. The common view of a product platform is as a collection of different parts that can be combined into a variety of products [4], such as for example Lego.

The physical building blocks that constitute these platforms are created with a fixed set of customer requirements in mind. Therefore, they are sub-optimal for businesses where customers demand new functionality, resulting in large or frequent changes to the product, for example products with low manufacturing volumes. In short, they support a low number of variants in manufacturing, but provides little support for development [5].

To address this, there are other ways to keep the efficiency over time. For example, reuse could incorporate more than physical parts. In literature, the term platform is comprehensive, essentially incorporating any form of reuse of design and manufacturing knowledge [6].

Gedell [7] argue that a design engineer need more information than just the physical form of a design, for example why a subsystem looks the way it does and what function it realizes in order to reuse a design. Alblas, Wortmann [8] suggest reuse on a higher level using function platforms. Isaksson et al. [9] address the trade between commonality of modules from a manufacturing perspective with product performance. These platforms enable reuse of functions and the possibility to generate engineering variants.

3.2. Manufacturing System Platforms

Manufacturing platforms in various forms are discussed by [10] as well as [11]. The former uses modularization of the product and the manufacturing system as a way to increase the efficiency of development and manufacturing. The latter, Michaelis, describes how co-development of the product and manufacturing system platforms can be performed. Gedell et al. [12] speak of a unified product and manufacturing system platform. Michaelis et al. [13] also describe the use of functional models for representing manufacturing system platform, and how these can be linked to the product platform using operations as connecting elements. Koren et al. [14] suggests a reconfigurable manufacturing system, which accommodates the variety of a product family. The configuration serves to quickly adjust to changing customer requirements, while flexibility of the system itself serves the product family variation.

3.3. A Platform Model

To efficiently support manufacturing aspects into the product concept phase, platform models need to support modeling of both domains and the connections between them. Claesson [15] initiated the configurable component (CC) concept – a product platform model that was later extended to include the manufacturing system and manufacturing operations [16]. The model builds on reuse of functional features and supports the concept development phase through object oriented modeling and enhanced function-means (EF-M) modeling [17]. The CC concept features modeling of systems with alternative design solutions – the modular bandwidth, and parametric ranges – the scalable bandwidth, from which a number of different variants may be configured.

A platform described with the CC concept consists of several generic systems, each described with one CC object. CC objects can *use* other CC objects to compose themselves. A CC object can represent for example an entire aircraft, an engine or a part of the engine frame. Essentially, the CC

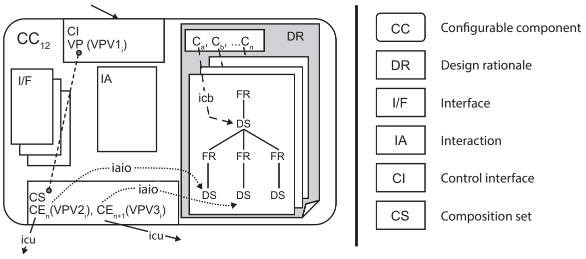

Fig. 1. The building blocks and relations of a configurable component (CC); composition element (CE), variant parameter (VP), variant parameter value (VPV), functional requirement (FR), design solution (DS), constraint (C), is composed using (icu), is an implementation of (iaio), is constrained by (icb) (adapted from [15])

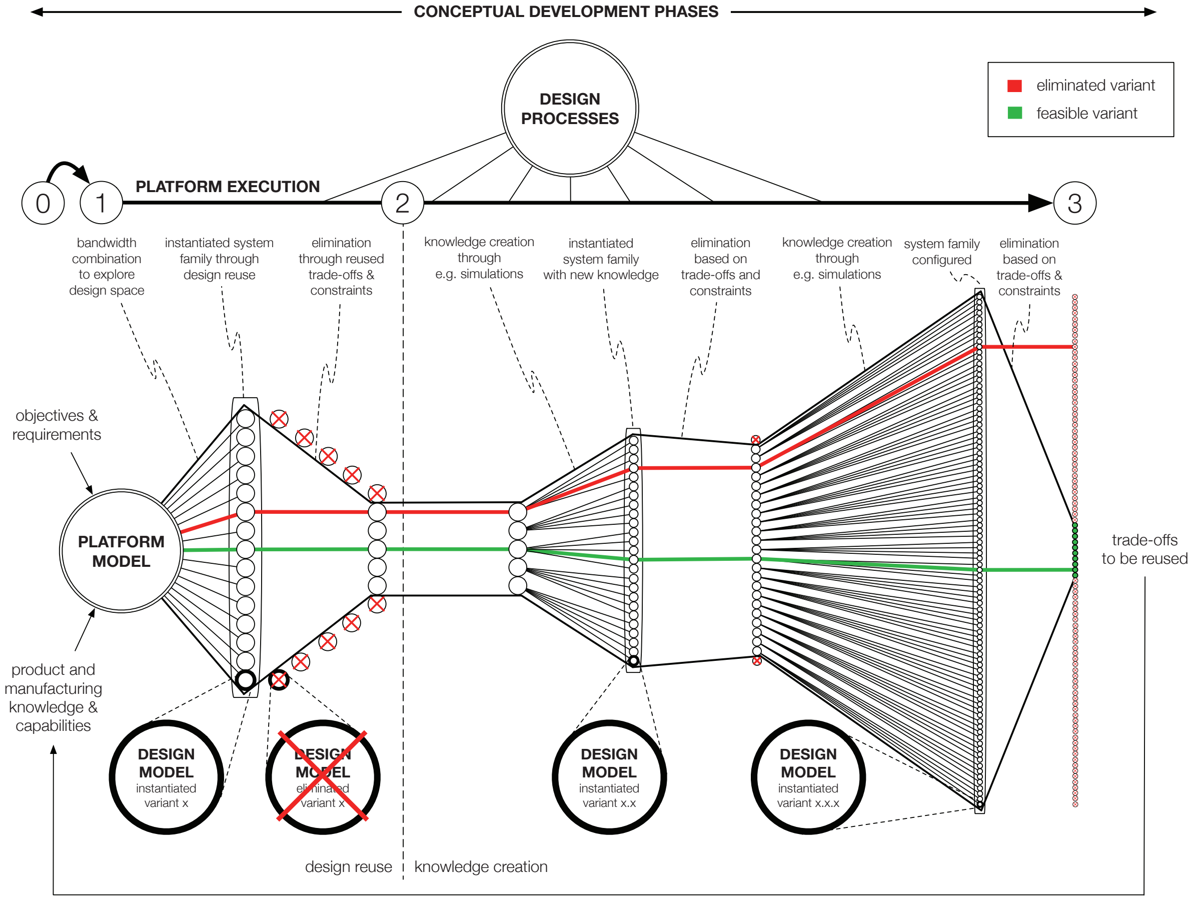

Fig. 2. The platform execution process can be used by design and manufacturing engineers to 1) explore design space through reuse of knowledge and capabilities, 2) gain new knowledge, such as trade-offs, about a set of conceptual product variants by linking, arranging and executing simulations, and 3) consecutively eliminate unfeasible conceptual product variants with support from trade-offs and constraints

objects do not represent just one engine, but rather every engine in the product platform. Depending on the inserted parameters you get different variants, and the engine will look or behave differently. One advantage with the CC concept compared to other platform approaches is that the platform development does not have to rely on fixed interfaces between systems in order to achieve concurrency. Rather, the interfaces are subject to scalable configuration, thus keeping the design flexibility for a longer time in the development process.

The building blocks of the CC object can be seen in Fig. 1. The *variant parameters* (VPs) express in what dimensions the CC can vary. Thus, the ranges of these determine the bandwidth of a CC. The CC object is instantiated through setting specific values (VPVs) to the VPs. These are accessed through the *control interface* (CI), which is an object that exposes the VPs externally. Each element has a *parameter set*, which describes the full bandwidth of the element; similar to the way the VPs describe the bandwidth of the CC. The parameter map is a mapping between the VPs and the parameter sets, consequently it decides where and how the parameters are distributed to the respective element of the CC. The backbone of the CC, the *design rationale* (DR), describes a breakdown of the design, and how each part of the CC fulfills a function. The DR is manifested as an enhanced function-means tree, consisting of *functional requirements* (FRs), *design solutions* (DSs) and *constraints* (Cs) [18]. The DSs are solutions to the FRs and can be represented on different levels of abstraction.

3.4. Producibility in Design

There are several approaches to manufacturing in design, such as Design for Manufacturing (DfM) and Design for Assembly (DfA). These approaches provide design engineers with guidelines on how to design products to be producible. Producibility is defined as *"the capability to produce the product in a robust and efficient way to meet the design specifications for functions and reliability of the product"* Producibility advocates a strong link to product functions, characteristics and performance [19].

There are numerous variables that can be used to characterize producibility [20]. For example, geometrical robustness [21,22], accessibility in the assembly process [20] and process quality [19], which all relate to the producibility of manufactured products.

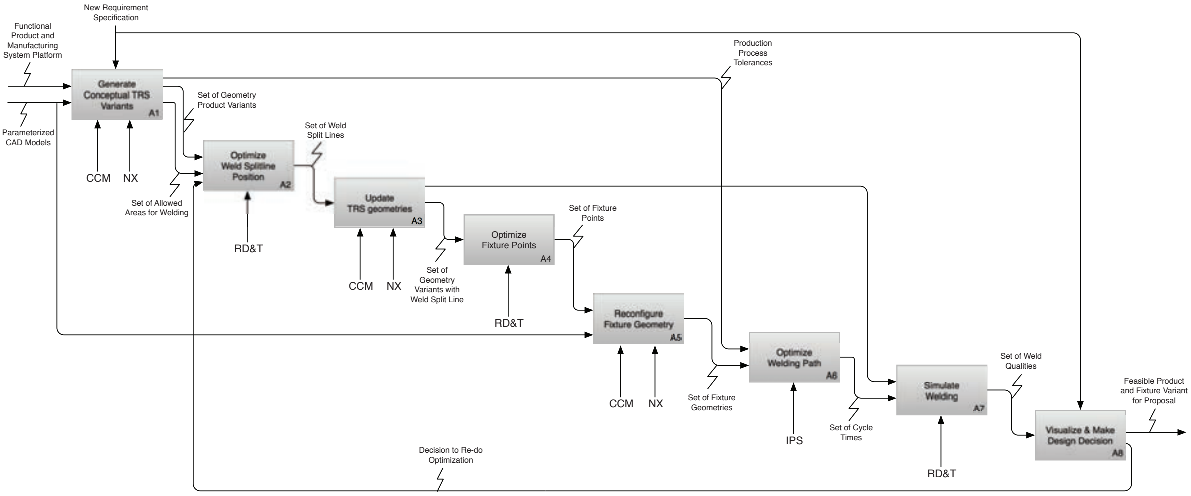

Fig. 3. An activity-based execution process, modeled using IDEF0

3.5. Product Life Cycle Management and Systems Integration

Stark [23] describes Product Lifecycle Management (PLM) as a widely recognized business approach for fast and efficient product development. It is a way to cope with an ever changing environment and still manage sustainable development.

PLM is more than an IT system. Stark [23] argues that there are several different parts of PLM, such as the engineering methods and processes, the organization, the product and the product information and IT systems that all need to be considered and coordinated. Svensson et al. [24] agree about that there are different views of PLM, other than systems, and pinpoints the views as *processes*, *information*, *systems* and *roles*. Their framework can be used to assess engineering information systems such as a PLM architecture.

As a system solution, PLM is an integrator of tools and technologies to facilitate swift and accurate information flow throughout the product lifecycle [25]. Product Data Management (PDM) systems may very well be one of the components of the PLM architecture [26], but are not to be considered to constitute the entire PLM strategy.

System integration is an essential issue in PLM. CAD systems are in general well integrated with the PDM system, and thus have access to the product meta data [26]. There are few satisfying examples of integration of Computer Aided Engineering (CAE) systems for cross-discipline analysis or synthesis during early phases of development. However, one promising example shows the feasibility of automated analysis of structural performance and manufacturing cost for a number of aircraft wings, and demonstrates the trade-off [27]. In most cases, however, information is manually transferred, or in some cases integrated in one direction only [26,28].

4. Suggested Approach

The suggested approach is framed using established design processes to support platform execution. These are, *set-based concurrent engineering* (SBCE) [2] – mapping the design space and consecutively eliminate unfeasible conceptual product variants based on knowledge, *the development funnel* [29] – systematically converge alternatives throughout the development phases, and *integrated product development* [30] – plan activities simultaneously across disciplines. In Fig. 2, the platform execution process is illustrated. Objectives and requirements are input to the platform model, which is prepared with company knowledge and capabilities of products and manufacturing systems. Based on the defined platform bandwidth, several conceptual product variants can be instantiated and explored. Already known trade-offs and capabilities can be reused to initially narrow down the design space. By preparing and arranging simulations, new knowledge, on a more detailed level, can be gained for each conceptual product variant, as unfeasible ones are systematically eliminated. The output of the execution process is 1) a number of feasible product variants, and 2) trade-offs, which can be used by design and manufacturing engineers to make design decisions, as well as to be stored in the integrated platform for future use.

To complete any simulation and derive knowledge about a family of conceptual product variants, sufficient software systems needs to be chosen, and a PLM architecture to be established. The PLM architecture evolves around a platform modeling and configuration tool (CCM), including platform models and processes, to which CAE tools for simulations are linked and arranged. CCM is used to collect the information produced by the CAx systems. CCM holds the platform model and the platform processes, shown in Fig. 2.

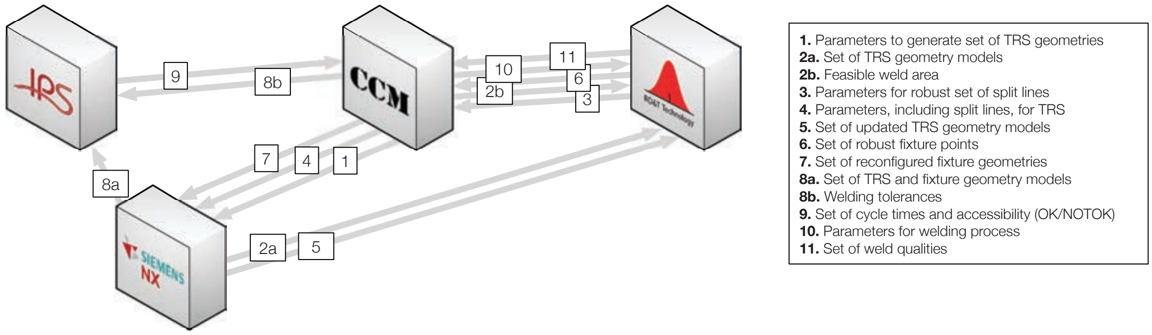

Fig. 4. CCM manages the platform model, and is used to collect data produced by RD&T, IPS and Siemens NX. RD&T and IPS use CAD models and weld process meta data to assess products' producibility.

5. Illustrative Case

To illustrate the approach, a case from the aerospace industry is demonstrated. The case company, GKN Aerospace Sweden AB, is a component supplier, responsible for mechanical design and manufacturing of static parts for aero engines. The studied product, Turbine Rear Structure (TRS), is located at the rear of the engine, and is illustrated in Fig. 5. Each TRS is currently manufactured at a yearly volume of approximately 400 units and is customized for different customer's requirements. Though, an expected increase of new engine variants is imminent.

The case company has the ambition to reduce the time, from a customer RFQ (Request for Quotation) to an offer of feasible conceptual alternatives, from three months to three weeks. To be prepared for such scenario, several phases of the product life-cycle needs to be assessed earlier in development than before. Especially, and typically, complex manufacturing processes affect time and product performance, why it is precarious not to assure a product's producibility before answering a customer RFQ.

The TRS can be manufactured in various ways and in different combinations, such as full cast, partly cast and partly welding, or partly cast, partly sheet metal pressing and partly welding. This case illustrates a welding assembly scenario, as the TRS is divided into segments, shown in Fig. 5.

A PLM architecture is prepared, linking a set of CAE tools to CCM, so that simulations can be applied to gain knowledge regarding producibility aspects of design, in conceptual phases of development. The CAE tools in this case are, software for Computer Aided Design (CAD) – SIEMENS NX, for Geometry Assurance and Robust Design – RD&T, and for Geometry and Motion Planning – IPS. The PLM architecture is illustrated in Fig. 4. The arranged activities, the required software for each activity, and the needed input and consequent output between them are illustrated in Fig. 3.

Fig. 5. An aero engine with the TRS highlighted in red, and the TRS component with its assembly arrangement due to welding accessibility

Initially, a number of geometry variants are configured by applying different sets of parameters to parameterized CAD models (1). These are sent, with weldable areas, to RD&T for optimization of the position of the weld split lines based on robustness analysis (2a, 2b). The result is sent back to CCM (3) as the parameters are used to update the CAD models (4). The CAD models are sent back to RD&T (5) that optimizes the fixture points to minimize the geometric variation in fixturing. These points are sent back to CCM (6) and used to reconfigure the fixture geometry models (7). The second CAE tool, IPS, uses the CAD models of the TRS and fixture (8a) as well as welding tolerances (8b) to simulate the robot movement for welding of each TRS variant. The cycle times, and a set of accessibility assessments (OK/NOTOK) are sent back to CCM (9). Thereafter, RD&T simulates the weld operation using the robot paths, CAD models and welding process parameters (10). The weld qualities are sent back to CCM (11) for use in the producibility assessment. Based on the collected information, designs that are inferior in terms of producibility can be eliminated.

6. Conclusions

This paper has focused on the producibility aspects of assembly through welding. The case study shows that it is possible to set up a PLM architecture to support producibility assessments of conceptual product variants. By using an integrated product and manufacturing system platform, it is possible to generate producible product variants in early development phases, in the context of assessed manufacturing aspects. Knowledge from manufacturing engineers can be distributed through the integrated platform to support design decisions related to producibility aspects. Through that, the approach can be considered valid for an integral part of conceptual phases of concurrent product and production development.

The PLM architecture consists of four different software components: one CAD tool for geometry modeling, two CAE tools for producibility assessments; and a platform modeling and configuration tool to keep track of the process and data, and to apply the configuration rules.

Automating steps in the platform execution process makes the process more efficient by leaving only important decisions to the design and manufacturing engineers. The design engineers will have more time for value adding activates as compared to tedious keyboard mashing and testing of different possible configurations before finding a feasible variant.

The case is simplified yet representative for GKN Aerospace. It was developed in close collaboration with industrial partners. The suggested approach has received traction for further studies of interdisciplinary platforms and producibility.

The suggested approach is tailored for early conceptual CAD models. The use of producibility assessments through simulations, only using conceptual models, may not provide a fully reliable final producibility. It does though ease the balancing of product performance and manufacturing capability, which is a typical trade-off for aerospace products.

Because welding processes are complex, the suggested approach holds great promise to be implemented and virtually assessed for all sorts of producibility aspects, related to manufacturing time, cost and quality. As physical testing and verification requires mature design models and expensive prototyping, virtual assessments of producibility is a necessity to answer requests faster. Without it, there is a risk of committing to designs that turn out costly, or inferior in manufacturing.

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